Microbial Curing of Cement for Energy Applications

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Team Members: Lawrence Livermore National Lab, University of Arizona

Project Goal

Cast-in-place carbonate cement concrete that cures via microbial activity to create monoliths of any length scale.

Total project cost:	$2.9M
Current Q / Total Project Qs	Q9 / Q12

TINA-Cement
Annual Meeting
October 13 & 14, 2021

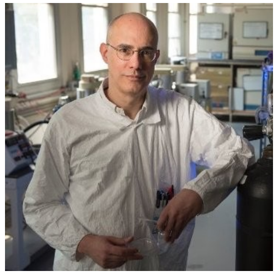
The Team

- Rutgers University (RU) – **Richard Riman**, Daniel Kopp, Paniz Foroughi
  – Cement & Concrete formulation, curing, and testing
  – Tech2Market Analysis

- Lawrence Livermore National Labs (LLNL) – **Yongqin Jiao**, Mimi Cho Yung, Michael Guzman, Michael Homel, Jaisree Iyer
  – Microbial Engineering
  – Mechanical & Chemical Modelling

- University of Arizona (UofA) – **Hongyue Jin**, Nighat Chowdhury
  – Process optimization for sustainability
  – LCA & TEA

Richard Riman



Yongqin Jiao

Hongyue Jin

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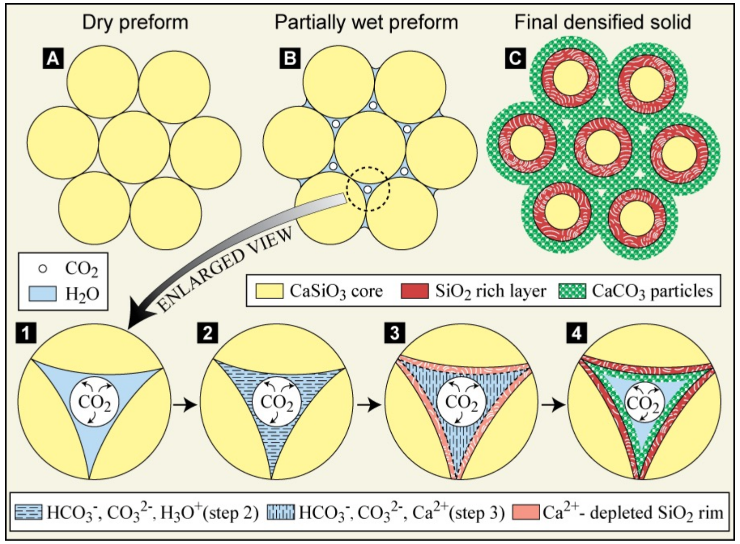
Background (Carbonate Cement)

Carbonate Cement ($CaSiO_3$) – cement cures via a CO_2 gas aqueous solution reaction with $CaSiO_3$ to create a durable carbonate-bonded structure.

- Invented at Rutgers
- Commercialized by Solidia Technologies
- Process has thickness limitations
- Requires CO_2 supply chain



A. Pack particles of $CaSiO_3$

B. Infiltrate particle bed with CO_2

C. Pore-bound reactive crystal growth fills pores

$$CaSiO_3 + CO_2 \rightleftharpoons CaCO_3 + SiO_2$$

Rutgers Cement IP Database (US Only, filings in 19 Regions)

US Patent #/Publication #/US Serial #	Title	Earliest Priority Date
US 9,216,926	Synthetic Formulations And Methods Of Manufacturing	06/09/11
US 8,313,802	Method of Hydrothermal Liquid Phase Sintering Of Ceramic Materials And Products Derived Therefrom	11/15/07
US 8,709,960	Method of Hydrothermal Liquid Phase Sintering Of Ceramic Materials And Products Derived Therefrom (D)	11/15/07
US 8,114,367	Systems And Methods For Carbon Capture And Sequestration And Compositions Derived Therefrom	11/15/07
US 8,721,784	Systems And Methods For Carbon Capture And Sequestration And Compositions Derived Therefrom (D)	11/15/07
US 9,095,815	Systems And Methods For Carbon Capture And Sequestration And Compositions Derived Therefrom (C)	11/15/07
US 9,266,147	Precursors And Transport Methods For Hydrothermal Liquid Phase Sintering	10/01/12
US 9,868,667	Bonding Element, Bonding Matrix And Composite Material Having The Bonding Element, And Method of Manufacturing Thereof	03/05/11
US 10,266,448	Bonding Element, Bonding Matrix And Composite Material Having The Bonding Element, And Method of Manufacturing Thereof (D)	03/05/11
US 10, 315,357	A method of producing a monolithic body from a porous matrix includes using low temperature solidification in an additive manufacturing process.	10/6/13
US 2014/0272216 (Allowed)	Aerated Composite Materials And Methods Of Production Thereof	03/13/13
16/257,544	Bonding Element, Bonding Matrix And Composite Material Having The Bonding Element, And Method of Manufacturing Thereof (C)	03/05/11
US 2019/0039960	Aerated Composite Materials And Methods Of Production Thereof (C)	03/13/13
WO 2016/112022	Sustainable Supply of Recipe Components	01/05/15

(D): Divisional

(C): Continuation

The Concept

Objective: develop a castable/pourable, self-curing carbonate cement concrete using CO_2 produced internally via microbes

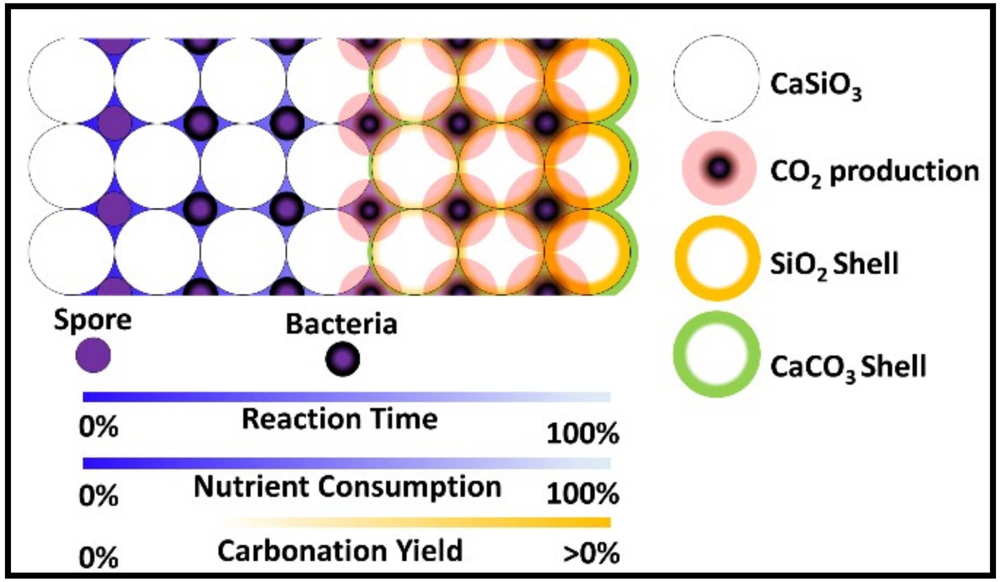
Summary

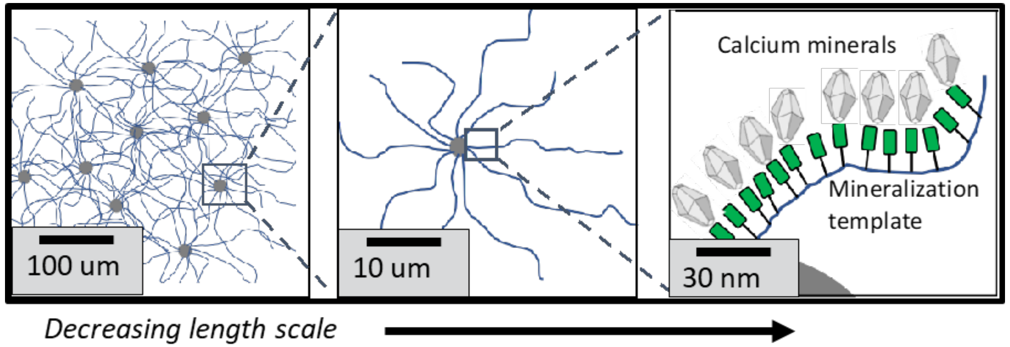
- *A mix containing bacteria, low-carbon cement, & aggregate*
- *Activated by addition of nutrient solution to mix*
- *CO_2 released by bacteria hardens concrete*
- *Any thickness can be cast and solidified*

Impact

- *CO_2 emissions reduced by up to nearly 3 Mt/y*
- *Reduced time and cost to complete construction projects*
- *Eliminates need for a CO_2 supply chain*
- *Viable cast-in-place technology*

Cast-in-place (Microbial)





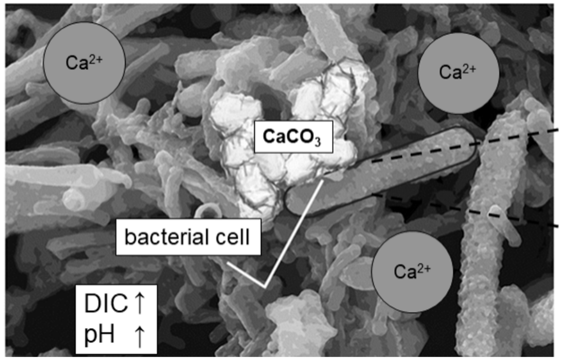
What is new about this project in the world of microbial curing?

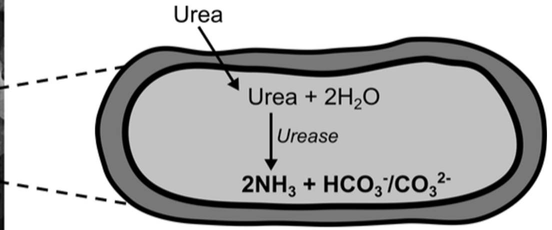
Prior work

- Cells were used to cure aqueous solutions of calcium
- All microbial work reported to date produces materials w/unacceptable mechanical properties (<5 MPa)
- Common concrete formulations not demonstrated

This Program

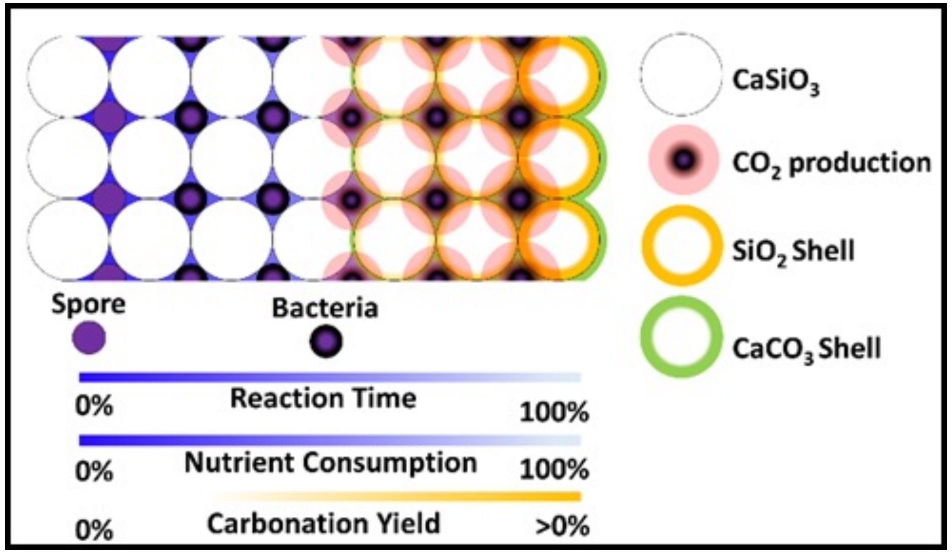
- Cells are used to cure cement particles sparingly soluble in aqueous solution
- Probes the possible origins of poor mechanical properties
- Examines properties of cement, mortars and concrete systematically





Project Objectives

- Select a microbial strain:
  - Produces CO_2 from a nutrient
  - Tolerant of cement solution conditions & processing conditions
- Engineer the chemistry and microstructure to facilitate the microbial curing mechanism in both slurries and monoliths
- Develop a predictive model correlating microstructure w/mechanical performance
- Perform LCA & TEA to ensure no environmental or economic RED-FLAGS



Challenges and Risks

- **Challenges**:
  - Concrete processing creates basic pH conditions that are detrimental to microbial viability
  - Microbe and nutrient site occupancy needs to be in “the right place at the right time”
- **Risks:**
  - $CaCO_3$ precipitation is rate-limited by pH and Ca-solubility
  - Poor microbial viability in concrete processing conditions
  - Microstructure and surface chemistry degrade strength
  - Microbial production cost is too high

Project Timeline

0 – 12 Months

Milestones Achieved

1. Microbial strain down-selected
2. Generated thermodynamic and kinetic models
3. Generated microstructure pore-microbe-cement model
4. Sufficient carbonation of $CaSiO_3$ cements

12 – 24 Months

Milestones Achieved

1. Commercially viable storage & processing methods for microbes
2. Concrete with 10 MPa compressive strength (2”x2”x2” cylinders)

24 – 36 Months

Milestones in Progress

1. Scalable microbial concrete formulation
2. Cast & Cure concrete (4"x8")
3. Performance metrics:
   - Cl- Permeability (<<5000 C)
   - Compressive Strength (>25 MPa)
   - Flexural Strength (>6 MPa)
   - Creep measurement

First Markets?

- Anchors
- Sidewalks
- Road-beds
- Curbs
- Pre-cast (thick)
- Concrete Repair

Start

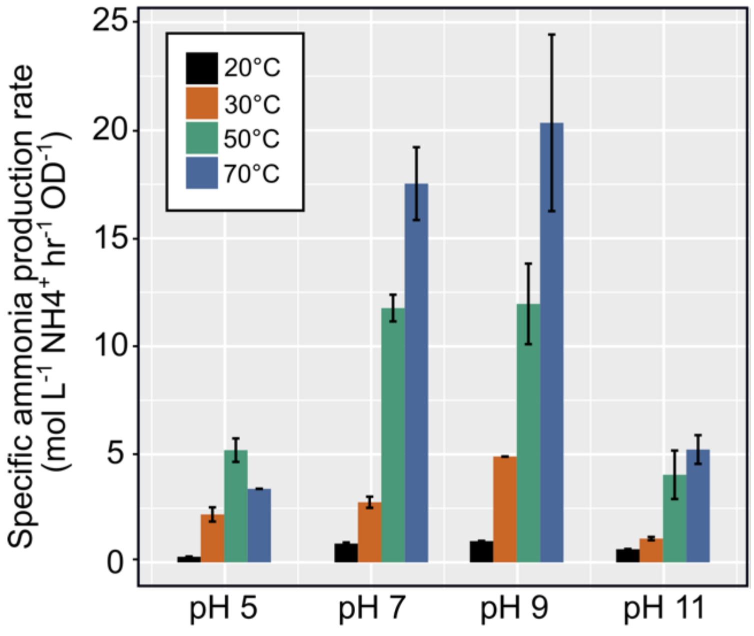
End

29 months elapsed

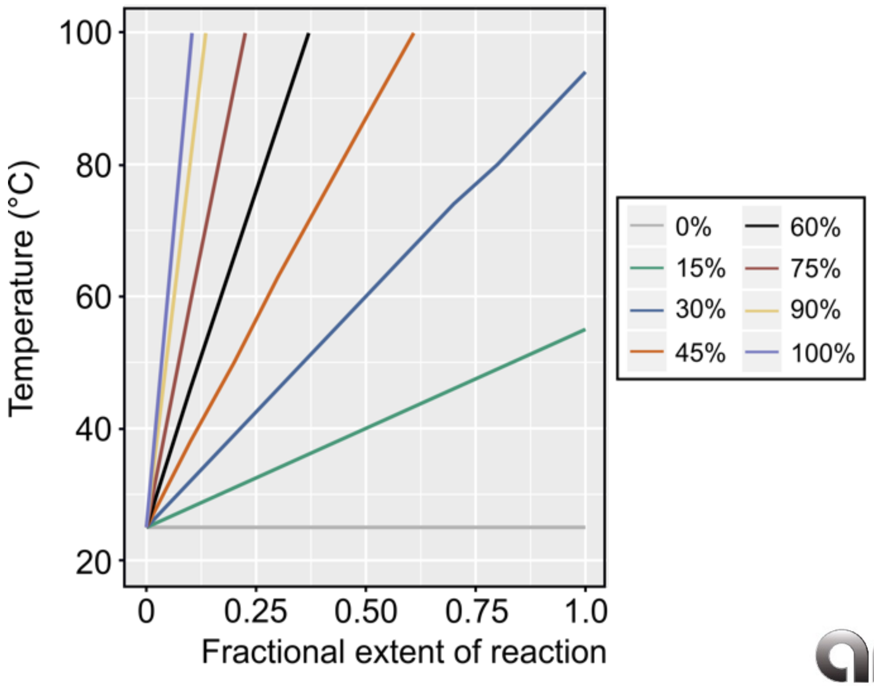
Results - Cement is a harsh environment for biology

- pH easily surpasses 11 to kill cells, best below 9
- Carbonation exotherm can kill cells about 70˚C
- **Cell strain** was down-selected & viability (cell survival) was demonstrated for all practical concrete processing conditions

Microbial Viability

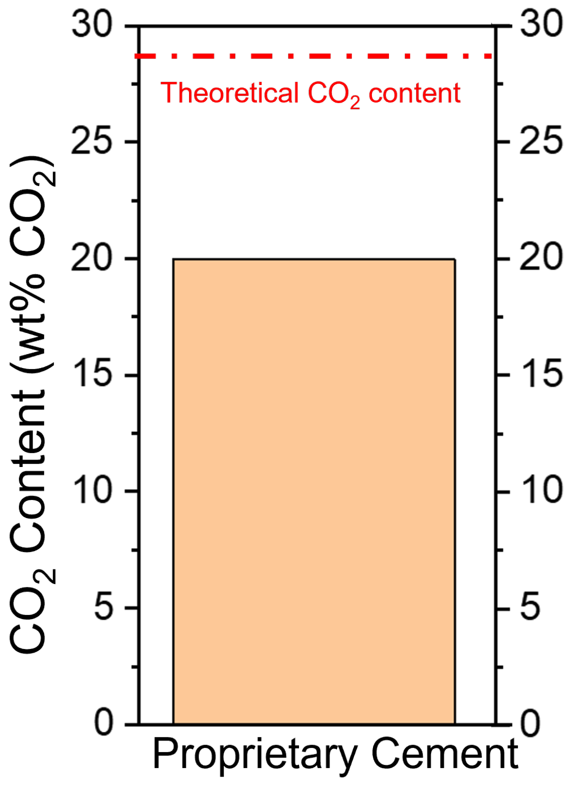


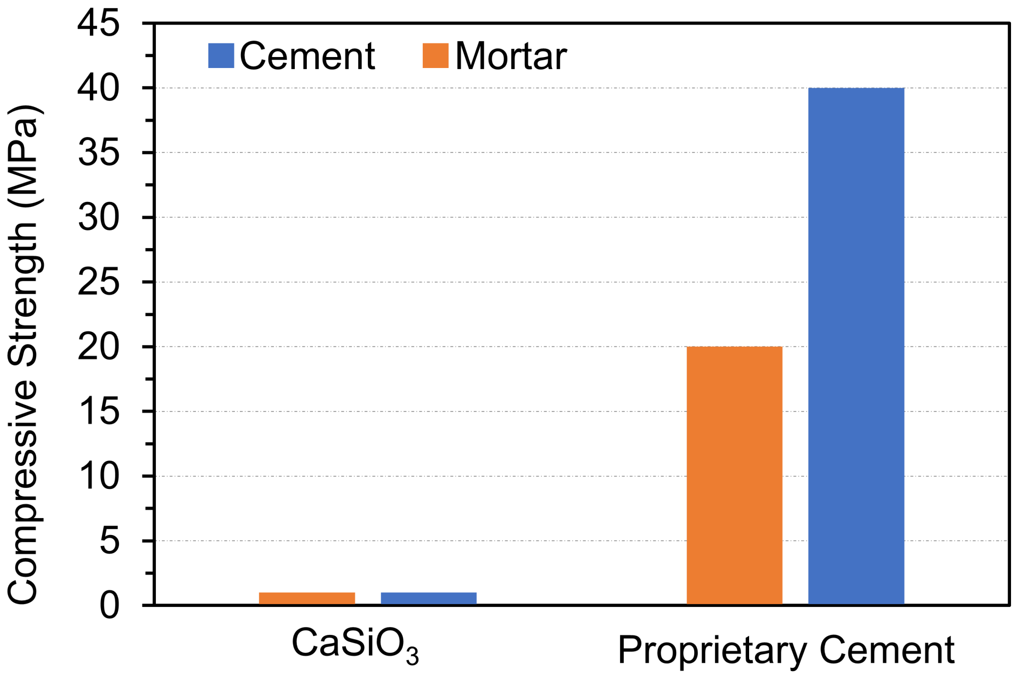
Self-heated Cement



Results – Carbonation and Strength

- Carbonation on the order 70% of theoretical is possible
- Strength between 20-40 MPa is possible
- $CaSiO_3$ cannot be used as a source of calcium to achieve these results





Technology-to-Market

- **Commercialization Strategy**: License technology for curing operations
- **Potential First Markets:** Anchors, Sidewalks, Road-beds, Curbs, Pre-cast (thick), Concrete Repair

Biological operations

Cell suppliers:
Strains for versatile use under-
- warm climates
- cooler climates
- seasonal climates

Curing operations

Concrete products:
- Precast (thick section)
- Cast-in-place/ready-mix (thick section)
- Thick coatings

Urea suppliers:
- Traditional approach
- Low carbon footprint methods

Cement production

Cement suppliers:
- Low-cost, low-carbon footprint, Proprietary cement

Tech. for ammonia capture

Potential Partnerships – Research Needs

- Standardized Concrete Testing
- Concrete Processing
- Microstructure-strength Simulations
- Fractography
- In Situ Environmental SEM
- MR-CT Imaging Of Concrete
- Energy-dispersive X-ray Diffraction Under Mechanical Load

Summary

- A formulation has been defined containing bacteria, low-carbon footprint cement, & aggregate
- $CaSiO_3$ cannot be used in these formulations
- The formulation has the potential to carbonate ~70% of theoretical
- Strengths greater than 20 MPa are possible with cements and mortars
- Concrete work is next…

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